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Plant-based products: Explore a way forward for mosquito's management: A review

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Mosquitoes (Diptera: Culicidae) pose a serious threat to humans worldwide, known to transmit various pathogens that cause infectious diseases and arboviruses, which are viral diseases such as chikungunya, dengue, Rift Valley fever, yellow fever, malaria, elephantiasis, Murray Valley encephalitis, Japanese encephalitis, Saint Louis encephalitis virus, West Nile virus, Eastern equine encephalomyelitis virus, Highlands J virus, Everglades virus, and crosse encephalitis virus. The emergence of widespread insecticide resistance and the potential adverse environmental problems associated with synthetic insecticides have highlighted the need for alternative methods to control the spread of mosquito populations, making it an important research priority. Safe and innovative tools, such as plant-based repellents, have recently been implemented to enhance mosquito management strategies. Plant-based repellents play a crucial role in the development of natural products as alternatives to chemical control methods. Plant extracts and essential oils, which are biodegradable, target-specific, eco-friendly, and have potent effects against mosquitoes, are reviewed in this article. These plant-based repellents offer promising potential for effective mosquito management, providing a safer and environmentally friendly approach to control mosquito populations and reduce the spread of mosquito-borne diseases. Properly formulated and used in combination with other integrated vector management strategies, plant-based repellents can contribute to sustainable and effective mosquito control efforts.

Keywords: Essential oils, dengue, repellents, malaria mosquito, bio-products, management, biocontrol.

INTRODUCTION

More than 3000 mosquito species are found worldwide, many of which act as vectors of diseases such as dengue fever, yellow fever, malaria, chikungunya, filariasis, and encephalitis (Lawal *et al*., 2012; Kalita *et al*., 2013; Naseem *et al*., 2016). Approximately two million people are infected with diseases transmitted by Aedes mosquito species (Naseem *et al*., 2016), and more than 300 million people are infected with malaria transmitted by Anopheles mosquito species in third-world countries (Hardin *et al*., 2009). Usually, these vectors are managed using insecticides, which ensure their control but are not eco-friendly. Moreover, mosquitoes have developed resistance to some insecticides in various regions worldwide. In this scenario, repellents are considered alternative effective tools to manage these insect pests (Naseem *et al*., 2016).

Traditional plant products have been used for centuries, and many researchers have reported that plant derivatives possess the ability to act as insect growth regulators (IGRs), larvicides, repellents, and ovicidal pesticides (Das *et al*., 2003). Most people prefer to use natural products as medicines to treat diseases and as prophylactics, such as to repel blood-seeking arthropods that act as vectors of various diseases (Jaenson *et al*., 2006). Repellents play a significant role in preventing vector-borne diseases by reducing human-vector contact. Unlike vaccines and chemoprophylaxis, repellents are suitable as they are affordable and provide protection against a broad variety of vectors (WHO, 1995). Repellents are a useful tool to prevent vector-borne diseases in areas where on-ground control is not possible (Pitasawat *et al*., 2003).

***Plant products with insecticidal activity*:** Plant-derived products have been used in various parts of the world for repelling or killing mosquitoes, using whole plants or their

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extracts. Chemical substances extracted from plants can be useful as larvicides, repellents, deterrent agents, insect growth regulators, and oviposition attractants (Kweka *et al.*, 2008). Many plant derivatives from *Azadirachta indica* (Maliaceae), *Zanthoxylum marmatum* (Rutaceae), and *Curcuma aromatica* (Zingiberaceae) have been tested for their repellent actions against mosquitoes (Kalita *et al.*, 2013). The plant *Azadirachta indica* has gained extensive acceptance since ancient times as an antifeedant (Monzon *et al*., 1994; Kishore *et al*., 2011; Kishore *et al*., 2014) (Table 1). It has been shown that the methanol and benzene extracts derived from *Artemisia vulgaris* have excellent repellent activity against *Aedes aegypti* (Kalita *et al*., 2013). Various essential oils, such as thyme, citronella, eucalyptus, and calamus, have been found to be effective in killing mosquito larvae (Kishore *et al*., 2014)."

Neem; *Azadirachta indica*: *Azadirachta indica* (Meliaceae), commonly known as the Neem tree, is an evergreen, fast-growing tree that can reach a height of 12-24 meters. *Azadirachta indica* seeds contain about 99 biologically active compounds, including nimbin, *A. ndica*, nimbolides, and nimbidin, which are abundant. These compounds are responsible for various properties such as growth disruption, ovicidal activity, fecundity suppression, repellency, anti-feedant, and insect growth regulation. *Azadirachta indica* products have multiple modes of action, are less toxic to mammals, birds, and fish, and induce low resistance. Additionally, the insect growth regulation (IGR) activity of A. indica disrupts the defense system of the larval cuticle, making it easier for pathogens to penetrate the insect system (Dua *et al*., 2009).

Azadirachta indica seed oil contains many compounds that are effective against mosquitoes and other insects. It prevents feeding activities through chemoreception, likely due to volatile organic components. It also acts as an IGR by disrupting endocrine function and causing developmental aberrations (Hardin *et al*., 2009). Most of the plant oils and extracts have a repellent effect against mosquitoes that can last from several minutes to several hours (Maia and Moore, 2011). A 2% formulation of *A. indica* oil in coconut oil provided complete protection from Anopheles mosquitoes for 12 hours (Peterson and Coats, 2001). *Azadirachta indica* oil emulsion in water has been proven effective in preventing the breeding of *Aedes aegypti*, *Culex quinquefasciatus*, and *Anopheles stephensi* in tanks, coolers, and swimming pools for a period of three weeks (Dua *et al*., 2009).

***Methanol fruit extracts*:** (*Solanum xanthocarpum*, *Atlantia monophyla* and *Swartzia madagascariensis)*

Solanum xanthocarpum (Solanaceae) is a major medicinal aromatic plant used in homeopathic medicines. It is known for its anti-asthmatic, antibacterial, hypoglycemic, and insect-repellent effects (Kumar *et al*., 2012). The methanolic extract of the leaves of *A. monophylla* has shown insect growth regulating (IGR), pupicidal, and larvicidal effects against mosquitoes (Basu and Basa, 1972). A crude extract of saponin from the pods of *Swartzia madagascariensis* resulted in higher mortality in larvae of *An. gambiae* compared to *Ae. aegypti* (Minijas and Sarda, 1986), and its efficacy is similar to that of a commercially available larvicide, namely fenthion (Amalraj and Das, 1996). This extract has 25 times more IGR activity against *Cx. quinquefasciatus* than methoprene, which is a juvenile hormone-mimicking compound. However, it is 7.5 times less effective than a chitin synthesis inhibitor (CSI), namely diflubenzuron (Robert and Olson, 1989). The efficacy of this plant extract is greater than that of various *A. indica* extracts, which have LC50 values ranging from 55 to 65 mg/l against mosquito larvae (Sivagnanam and Kalyanasundaram, 2004).

***Menthol derivatives*:** Peppermint oil extracted from the leaves of *Mentha piperita* L. has a long tradition of medicinal use and is well known as a mosquito larvicide due to the high concentration of menthol, which is the predominant aroma component of the oil. This essential oil has promising and significant repellent activity against *Ae. aegypti* adults (Kumar *et al*., 2011; Samarasekera *et al.*, 2008; Ansari *et al.*, 2000). The insignificant compounds of the oil, i.e., caryophyllene, menthone, methyl acetate, pinene, limonene, and pulegone, proved to be minimally or not effective against the mosquitoes. L-menthol derivatives were produced and tested for the first time for their knockdown effect and mortality against mosquitoes, namely *Ae. aegypti*, *C. quinquefasciatus*, and *An. tessellates*. Several derivatives, i.e., menthyl cinnamate, menthyl chloroacetate, thymol, menthone glyceryl acetal, terpineol, and mugetanol, showed enhanced mosquitocidal activity against the tested species of mosquitoes (Samarasekera *et al*., 2008). Adults emerged from larvae exposed to this oil have a reduced rate of fecundity and fertility (Ansari *et al*., 2000).

***Essential oils*:** Essential oils are naturally volatile substances (Neiro *et al.*, 2010 and Rehman *et al.*, 2014) that are present in various plants and are utilized commercially in several ways, including as flavor enhancers in food products, pharmaceuticals, insecticides, and odorants in fragrances. They are known for their antifungal, insecticidal, and antibacterial properties (Rajkumar and Jebanesan, 2007). Essential oils and their derivatives have been found to effectively control mosquitoes and degrade quickly in the environment, making them environmentally friendly. They are generally non-toxic to birds, mammals, and aquatic ecosystems when used according to guidelines, making them "green" pesticides (Kalita *et al*., 2013). Secondary metabolites of many plant species have biological ability. Among these, essential oils and their constituents have garnered attention as potential bio-pesticides due to their anti-feedant, anti-reproductive, insecticidal, and repellent effects, act as insect growth regulators (IGRs) against mosquito species (Hardin *et al.*, 2009). The bio-pesticides are synthesized by combining various plant extracts with edible

Table 1. Insecticidal activity of plant extracts and derivatives against mosquitoes.

Compound	Species	LC_{50} (mg/l)	LC_{90} (ml)	KD_{50}	LT_{50} @ 200 ppm (h)	Effect	Reference
Atlantia monophylla	*Aedes aegypti*	0.09	0.33	-	-		Sivagnaname and
(methanolic extracts)	*Culexquinquefasciatus*	0.14	0.30	-	-	Larvicidal	Kalyanasundaram
	Anopheles stephensi	2.03	6.06	-	-		2004
	Aedes aegypti	0.07	0.26	-	-		Sivagnaname and
	Culex quinquefasciatus	0.07	0.10	-	-	Pupicidal	Kalyanasundaram
	Anopheles stephensi	0.05	0.12	-	-		2004
	Aedes aegypti	0.07	0.26	-	-	Insect	Sivagnaname and
	Culex quinquefasciatus	0.07	0.10	-	-	growth	Kalyanasundaram
	Anopheles stephensi	0.05	0.12	-	-	regulating	2004
Menthol	*Aedes aegypti*	N/A	-	N/A	-		Samarasekera *et al.,*
	Culex quinquefasciatus	0.50 (0.32-0.76)	-	0.50 (0.41-0.62)	-	Insecticidal	2008
	Anopheles tessellatus	0.36 (0.24-0.45)	-	0.54 (0.46-1.04)	-		
Menthone	*Aedes aegypti*	N/A	-	N/A	-		Samarasekera *et al.,*
	Culex quinquefasciatus	N/A	-	N/A	-		2008
	Anopheles tessellatus	4.31 (3.05-7.23)	-	N/A	-		
Menthyl acetate	*Aedes aegypti*	N/A	-	N/A	-		Samarasekera *et al.,*
	Culex quinquefasciatus	0.76 (0.07-1.35)	-	1.27 (1.13-1.44)	-		2008
	Anopheles tessellatus	N/A	-	N/A	-		
Menthyl chloroacetate	*Aedes aegypti*	0.75 (0.58-0.93)	-	0.62 (0.16-0.90)	-		Samarasekera *et al.,*
	Culex quinquefasciatus	0.26 (0.13-0.36)	-	0.40 (0.03-0.61)	-		2008
	Anopheles tessellatus	0.08 (0.06-0.11)	-	0.57 (0.42-0.74)	-		
Menthyl	*Aedes aegypti*	2.01 (1.69-3.05)	-	1.80 (1.49-2.57)	-		Samarasekera *et al.,*
dichloroacetate	*Culex quinquefasciatus*	1.41 (1.10-1.99)	-	0.30 (0.04-0.72)	-		2008
	Anopheles tessellatus	0.46 (0.19-0.63)	-	0.86 (0.69-1.03)	-		
Menthyl methyl ether	*Aedes aegypti*	N/A	-	N/A	-		Samarasekera *et al.,*
	Culex quinquefasciatus	N/A	-	N/A	-		2008
	Anopheles tessellatus	N/A	-	N/A	-		
Menthyl lactate	*Aedes aegypti*	N/A	-	N/A	-		Samarasekera *et al.,*
	Culex quinquefasciatus	2.32 (2.16-2.52)	-	1.55 (1.18-2.54)	-		2008
	Anopheles tessellatus	0.80 (0.44-1.42)	-	0.59 (0.40-0.73)	-		
Menthylcinnamate	*Aedes aegypti*	3.37 (2.59-6.06)	-	2.71 (2.24-3.66)	-		Samarasekera *et al.,*
	Culex quinquefasciatus	0.65 (0.48-0.86)	-	1.05 (0.80-1.36)	-		2008
	Anopheles tessellatus	0.82 (0.59-1.09)	-	1.65 (1.31-2.25)	-		
Menthyl anthranilate	*Aedes aegypti*	N/A	-	N/A	-		Samarasekera *et al.,*
	Culex quinquefasciatus	N/A	-	N/A	-		2008
	Anopheles tessellatus	N/A	-	N/A	-		
Menthyl benzoate	*Aedes aegypti*	N/A	-	N/A	-		Samarasekera *et al.,*
	Culex quinquefasciatus	N/A	-	N/A	-		2008
	Anopheles tessellatus	0.90 (0.51-1.43)	-	0.62 (0.34-0.86)	-		
Menthyl	*Aedes aegypti*	N/A	-	N/A	-		Samarasekera *et al.,*
pivalate	*Culex quinquefasciatus*	N/A	-	N/A	-		2008
	Anopheles tessellatus	N/A	-	3.62 (2.86-3.98)	-		
Menthyl propionate	*Aedes aegypti*	N/A	-	N/A	-		Samarasekera *et al.,*
	Culex quinquefasciatus	N/A	-	N/A	-		2008
	Anopheles tessellatus	1.82 (1.53-2.49)	-	2.11 (1.68-4.18)	-		
Menthone	*Aedes aegypti*	N/A	-	N/A	-		Samarasekera *et al.,*
	Culex quinquefasciatus	N/A	-	N/A	-		2008
	Anopheles tessellatus	4.31 (3.05-7.23)	-	N/A	-		
Mugetanol	*Aedes aegypti*	0.55 (0.34-0.75)	-	0.31 (0.16-0.44)	-		Samarasekera *et al.,*
	Culex quinquefasciatus	0.17 (0.02-0.32)	-	0.17 (0.03-0.29)	-		2008
	Anopheles tessellatus	0.55 (0.34-0.75)	-	0.31 (0.16-0.44)	-		
Methyl	*Aedes aegypti*	N/A	-	N/A	-		Samarasekera *et al.,*
chloropropionate	*Culex quinquefasciatus*	2.36 (2.20-2.61)	-	2.02 (1.65-2.75)	-		2008
	Anopheles tessellatus	0.28 (0.22-0.35)	-	0.34 ()0.26-0.44	-		
Menthylcarboxamide	*Aedes aegypti*	1-0.5	-	N/A	-		Samarasekera *et al.,*
	Culex quinquefasciatus	N/A	-	N/A	-		2008
	Anopheles tessellatus	1.22 (0.93-1.87)	-	2.23 (1.85-2.85)	-		
β-Caryophyllene	*Aedes aegypti*	N/A	-	N/A	-		Samarasekera *et al.,*
	Culex quinquefasciatus	5.29 (3.55-12.59)	-	2.22 (1.82-2.80)	-		2008
	Anopheles tessellatus	0.80 (0.42-1.20)	-	1.03 (0.55-2.12)	-		
Menthyltrifluroacetate	*Aedes aegypti*	N/A	-	N/A	-		Samarasekera *et al.,*
	Culex quinquefasciatus	N/A	-	N/A	-		2008
	Anopheles tessellatus	2.18 (1.70-3.79)	-	2.66 (2.24-5.15)	-		
	Aedes aegypti	N/A	-	1.22 (0.97-2.22)	-		

Compound	Species	LC_{50} (mg/l)	LC_{90} (ml)	KD_{50}	LT_{50} @ 200 ppm (h)	Effect	Reference
Menthone glyceryl acetal	*Culex quinquefasciatus*	0.46 (0.36-0.65)	-	0.79 (0.51-3.23)	-		Samarasekera *et al.*, 2008
	Anopheles tessellatus	0.95 (0.78-1.09)	-	0.19 (0.11-0.26)	-		
Pulegone	*Aedes aegypti*	5.25(4.06-10.5)	-	3.27 (2.59-5.43)	-		Samarasekera *et al.*, 2008
	Culex quinquefasciatus	3.31 (2.74-5.0)	-	1.62 (1.19-2.45)	-		
	Anopheles tessellatus	1.33 (0.88-2.31)	-	0.84 (0.57-1.22)	-		
α-Terpiniol	*Aedes aegypti*	0.62 (0.54-0.98)	-	0.75 (0.58-1.13)	-		Samarasekera *et al.*, 2008
	Culex quinquefasciatus	0.56 (0.47-0.71)	-	0.59 (0.48-0.76)	-		
	Anopheles tessellatus	0.45 (0.35-1.05)	-	0.59 (0.44-2.40)	-		
Thymol	*Aedes aegypti*	0.66 (0.55-0.90)	-	0.49 (0.39-0.65)	-		Samarasekera *et al.*, 2008
	Culex quinquefasciatus	0.71 (0.59-0.88)	-	0.60 (0.50-0.77)	-		
	Anopheles tessellatus	0.45 (0.35-1.05)	-	0.59 (0.44-2.40)	-		
Curcuma longa L. (Zingiberaceae) (Essential oil source in plant)	*Aedes aegypti*	-	-	-	6.32 ± 0.75	Larvicidal	(Zhu *et al*., 2008)
	Aedes albopictus	-	-	-	9.28 ± 2.93		
	Culex pipiens	-	-	-	0.90 ± 0.02		
Eucalyptus citriodora Hook. (Myrtaceae) (Essential oil source in plant)	*Aedes aegypti*	-	-	-	1.12 ± 0.39		(Zhu *et al*., 2008)
	Aedes albopictus	-	-	-	0.85 ± 0.39		
	Culex pipiens	-	-	-	0.12 ± 0.04		
Santalum album L. (Santalaceae) (Essential oil source in plant)	*Aedes aegypti*	-	-	-	1.06 ± 0.11		(Zhu *et al*., 2008)
	Aedes albopictus	-	-	-	1.82 ± 0.06		
	Culex pipiens	-	-	-	1.55 ± 0.07		
Cinnamomum cassia L. (Lauraceae) (Essential oil source in plant)	*Aedes aegypti*	-	-	-	1.09 ± 0.11		(Zhu *et al*., 2008)
	Aedes albopictus	-	-	-	11.04 ± 3.28		
	Culex pipiens	-	-	-	3.12 ± 0.18		

Table 2. Plant essential oils having high repellency against mosquitoes.

Mosquito	Plant source	Plant part	Reference
Aedes aegypti	*Zanthoxylum piperitum*	Dried fruit	Choocote *et al*., (2007)
	Ocimum basilicum	Leaves	Prajapati *et al*., (2005)
	Cinnamomum zeylanicum	Bark	Prajapati *et al*., (2005)
	Rosmarinus officinalis	Shoot	Prajapati *et al*., (2005)
	Zanthoxylum limonella	Leaves	Trongtokit*et al*., (2005)
	Cymbopogon nardus	Leaves	Trongtokit*et al*., (2005)
	Dianthuscaryo phyllum	Flowers	Tunón*et al*., (2006)
	Citronella	Commercial	Thomas *et al*., (2009)
	Allium sativum	Bulb	Sritabutra*et al*., (2011)
	Cymbopogan citratus	Leaves, stem	Phasomkusolsil & Soonwera (2012)
	Citrus sinensis	Fruit	Sritabutra*et al*., (2011)
	Curcuma longa	Plant oil	Phasomkusolsil & Soonwera (2010)
	Mentha piperita	Leaves	Kumar *et al*., (2011)
	Zanthoxylum limonella	Seed and fruit	Trongtokit*et al*., (2005)
	Azadirachta indica	Leaf & Seed	Monzon *et al*., (1994)
Anopheles gambiae	*Lippiaj avanica*	Leaves	Nzira *et al*., (2009), Omolo *et al*., (2004)
	Plectranthus marrubioides	Commercial	Omolo *et al*., (2004)
	Tarchonanthus camphoratus	Commercial	Omolo *et al*., (2004)
	Conzya newii	Commercial	Omolo *et al*., (2004)
	Corton pseudopulchellus	Information not available	Odalo*et al*., (2005)
	Makilua fragrans	Information not available	Odalo *et al*., (2005)
	Endostemon tereticaulis	Information not available	Odalo *et al*., (2005)
	Ocimum forskolei	Information not available	Odalo *et al*., (2005)
	Ocimum fischeri	Information not available	Odalo *et al*., (2005)
	Plectranthus longipes	Information not available	Odalo *et al*., (2005)
	Tetradenia riparia	Information not available	Omolo *et al*., (2004)
	Lippia ukambensis	Information not available	Omolo *et al*., (2004)
Anopheles stephensi	*Ocimum basilicum*	Leaves	Prajapati *et al*., (2005)
	Cinnamomum zeylanicum	Bark	Prajapati *et al*., (2005)
	Corymbia citriodroa	Commercial	Trongtokit*et al*., (2005)
	Cymbopogon nardus	Commercial	Trongtokit*et al*., (2005)
Aedes albopictus	*Eucalyptus globulus*	Commercial	Yang and Ma (2005)
Culexpipiens	*Pimpinella anisum*	Seed	Erler *et al*., (2006)

Mosquito	Plant source	Plant part	Reference
	Ocimum basilicum	Dried foliage	Erler *et al.*, (2006)
	Eucalyptus camaldulensis	Dried fruits	Erler*et al.*, (2006)
Culexquinquefasciatus	*Mentha piperita*	Fresh leaves	Ansari *et al.*, (2000)
	Rosmarinus officinalis	Shoot	Prajapati *et al*., (2005)
	Ocimum basilicum	Leaves	Prajapati *et al*., (2005)
	Cinnamomum zeylanicum	Bark	Prajapati *et al*., (2005)
	Cymbopogon winterianus	Leaves	Tawatsin *et al*., (2001)
	Solanum zanthocarpum	Fresh leaves	Rajkumar and Jebanesan (2005)
	Moschosma polystachyum	Fresh leaves	Rajkumar and Jebanesan (2005)
	Ocimum americanum	Leaves	Tawatsin *et al*., (2001)
	Zanthoxylum limonella	Leaves	Trongtokit*et al*., (2005)
	Pogostemon cablin	Commercial	Trongtokit*et al*., (2005)
	Syzygium aromaticum	Commercial	Trongtokit*et al*., (2005)
	Citrus sinensis	Plant oil	Phasomkusolsil & Soonwera (2010)
	Zanthoxylum limonella	Seed and fruit	Trongtokit*et al*., (2005)
	Mylol oil	Commercial	Ansari *et al.*, (2000)
	Plectranthus marrubioides	Commercial	Trongtokit*et al*., (2005)
	Zanthoxylum limonella	Plant oil	Phasomkusolsil & Soonwera (2010)
	Cymbopogon nardus	Commercial	Trongtokit *et al*., (2005)
	Zingiber Cassumunar	Plant oil	Phasomkusolsil & Soonwera (2010)
	Eugenia caruophyllus	Leaves	Trongtokit *et al*., (2005)
	Azadirachta indica	Leaf & Seed	Monzon *et al.*, (1994)
Anopheles dirus	*Curcuma longa*	Rhizomes	Tawatsin *et al*.,(2001)
	Zanthoxylum limonella	Leaves	Trongtokit *et al*., (2005)
	Pogostemon cablin	Commercial	Trongtokit *et al*., (2005)
	Syzygium aromaticum	Commercial	Trongtokit *et al*., (2005)
	Zanthoxylum limonella	Seed and fruit	Trongtokit *et al*., (2005)

oils and other essential oils, which demonstrate their potential as larvicides against *Culex* mosquitoes. Numerous essential oils from different plant sources, such as eucalyptus, citronella, calamus, and thyme, have shown promising results as larvicides against mosquitoes (Kishore *et al*., 2011). The extracts of numerous plants, including neem (*Azadirachta indica*), thyme (*Thymus vulgaris* L.), citronella grass (*Cymbopogon nardus*), basil (*Ocimum americanum* L., *Ocimum gratissimum* L., *Ocimum basilicum* L.), prickly straggler (*Solanum trilobatum* L.), clove (*Syzygium aromaticum* L.), and musk basil (Mosquito) have been studied as mosquito repellents (Rajkumar and Jebanesan, 2007). The essential oils were assessed for their repellency effects against *Anopheles stevensi* using the human bait technique, as described by Fradin and Day (2002). Based on the study by Rajkumar and Jebanesan (2007), among the five essential oils studied, *M. charantia* and *T. procumbens* provided more than five hours of repellency at a concentration of 6 percent, while *P. guajava* and *C. asiatica* provided less than 2.30 hours of repellency. These essential oils did not cause hot sensations, skin irritation, or rashes on the arms of the test volunteers. Three out of the five essential oils that were distilled from *M. charantia*, *T. procumbens*, and *I. cairica* expressed promising repellent activity against *Anopheles* spp. Oils of eucalyptus, birch/pine tar, citronella, and lily have shown good repellent effects against *Ae. aegypti* and *An. Communis* (Thorsell *et al*.,1998). A list of essential oils that exhibit high repellent effects against various species of mosquitoes shown in Table 2.

***Future prospects*:** Insect repellents obtained from plant sources should be precise, human-friendly, and safe for non-target organisms. Combinations of natural plant products are also environmentally friendly and cost-effective agents for controlling insects. The use of botanical derivatives as substitutes for synthetic insecticides in mosquito control reduce costs and environmental hazards.
It is anticipated that repellent products can be used effectively at lower levels compared to toxic compounds, thereby reducing the pesticide load on the surrounding environment. The use of plant-based repellents may decrease the incidence of mosquito-transmitted diseases in remote areas and could also play a role in reducing mosquitoes in certain urban areas such as hospitals, schools, and food centers.

***Conclusion*:** In conclusion, natural products, such as essential oils, are essential components of repellent technology that may benefit humanity in the future. However, further studies are needed to fully understand their safety, efficacy, and environmental impact. Proper evaluation and implementation of plant-based insect repellents could potentially provide safer and environmentally friendly alternatives for mosquito control.

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